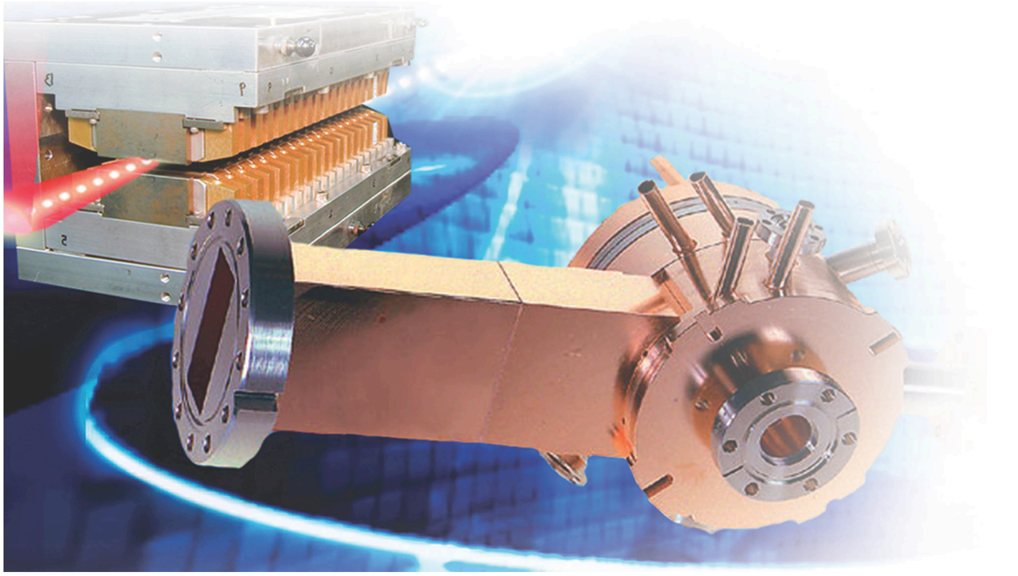

ATF Newsletter

Fall 2014

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ATF NAMED DOE'S FLAGSHIP FACILITY FOR ACCELERATOR STEWARDSHIP

ATF Status Update

Welcome to the ATF Fall newsletter. This quarter's edition is dedicated to the 17th ATF User Meeting that will take place on October 14-15 followed by a two-day Upgrade Workshop on October 16-17 (see https://indico.bnl.gov for meeting agendas).

Researchers working in accelerator science and technology as well as related fields are invited to submit proposals for review by the Program Advisory Committee at the ATF Users' Meetings. These events are an opportunity for present- and potential-ATF users to get together and discuss their recent achievements and future plans.

This year, our 17th ATF User Meeting is held in conjunction with the ATF Upgrade Workshop. The participants of this workshop will explore new opportunities for research in advanced accelerators and radiation sources offered by the ATF upgrade to 500 MeV in electron beam energy and 100 TW peak power output from a femtosecond CO_2 laser. The initiation of this pivotal facility upgrade coincides with the nomination of the ATF as the DOE HEP Flagship Accelerator Stewardship Facility. We are looking at the upcoming meetings as instruments to strengthen the ATF contribution at the forefront of advance accelerator and radiation source science and their multi-disciplinary applications.

This newsletter starts with a brief overview of the past quarter's experimental work, followed by two articles addressing the ATF present and future capabilities, which will be explored at the upcoming ATF meetings. The agendas for both meetings are attached. Finally, a detailed experiment report of recent activities in inverse Compton scattering will be presented.

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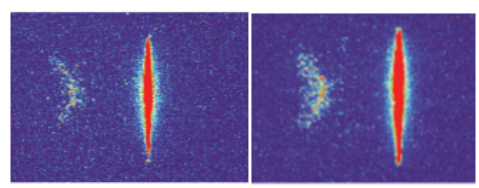

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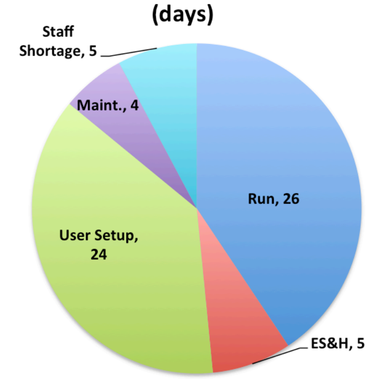

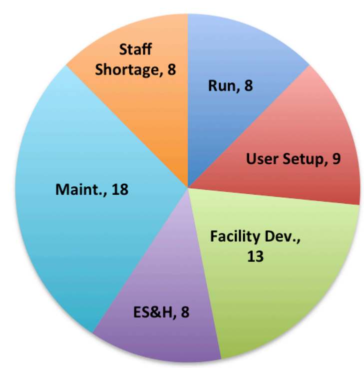

During this quarter the ATF played host to five different experiments, most notably the RUBICON IFEL experiment that ran in September – we hope to see the preliminary results at the User Meeting. Together with work on user experiments, time was devoted to progressing with the CO_2 power upgrade alongside installation of equipment in preparation for the Inverse Compton Source for Extreme Ultraviolet Lithography experiment. See right for a breakdown of e-beam and CO_2 laser activities. The following user experiments were served with typical ebeam parameters ranging from 45 – 70 MeV in energy and 30 – 500 pC charge and CO2 laser of 1 TW peak power:

AE35, High-brightness picosecond ion beam source based on BNL TW CO_2 laser - This group is currently investigating methods by which plasma density, generated by laser in gas jet, may be steepened to give optimal shock formation conditions for monoenergetic ion production.

AE41, RUBICON - 220mEv/M -130 MeV energy gain helical IFEL experiment at BNL – In their most successful run yet, this group from UCLA obtained excellent data which is now being processed for their user meeting presentation.

AF53, Nonlinear inverse Compton scattering – UCLA continued their pioneering studies of Compton harmonics and mass-shift effect using the high-power CO_2 laser. A more detailed commentary of their recent activities can be seen on page 4.

AF62, Surface Wave Accelerator and Radiation Source Based on Silicon Carbide – This feasibility study is still in the alignment phase. They intend to return early next year and will present their plans at the upcoming user meeting.

AF64, Sub-femtosecond beam line diagnostics – This experiment group performed the first test of their wiggler that will ultimately be used to demonstrate their sub-femtosecond beam diagnostics equipment, which is currently in development.

Recent Publications

High Quality Electron Beams from a Helical Inverse Free Electron Laser Accelerator, Joseph Duris *et. al.*, *Nature Comms, Vol. 5, 2014*

100-Terawatt CO2 Laser: Design and Current Status, M. N. Polyanskiy, M. Babzien, I. V. Pogorelsky, AAC'14

Future Compact Light Sources Driven by CO2 Lasers, Igor V. Pogorelsky and Alex Murokh, AAC'14

Solid-state Seeding of a High Power Picosecond Carbon Dioxide Laser, M. Babzien, I.V. Pogorelsky, M. Polanskiy, AAC'14

In Service of Accelerator Stewardship: The BNL ATF and its Upgrade, I. Ben-Zvi, I.V. Pogorelsky, AAC'14

Pulse compressor, M. N. Polyanskiy, Patent application S.N. 62/021,725

In Service of Accelerator Stewardship: The BNL ATF and its Upgrade

I. Ben-Zvi and I. Pogorelsky

Much of the U.S.'s work in accelerator science and engineering is conducted in the Department of Energy's National Laboratories; nevertheless, researchers from universities and small businesses also play a vital role. The important question is how can these diverse groups afford to undertake state-of-the-art experimental research to explore bold new ideas, test new techniques, and prove theoretical models? The answer is clear: It lies in the ready availability of modern user facilities. Indeed, user facilities are the mainstay of many sciences, and, by hosting a free service for users, they deter waste and duplication of efforts. Invaluably, they enable investigators with a small research budget to carry out their experimental work using high-performance accelerators and lasers, supported by experts dedicated to this task.

Over a quarter of a century ago, the Brookhaven Accelerator Test Facility (ATF) pioneered the concept of a user facility for advanced accelerator research. Established by two visionaries in accelerator science, Bob Palmer and Claudio Pellegrini, the ATF has served American researchers and scientists worldwide by offering incomparable opportunities for studying the complex properties of modern accelerators and new techniques of particle acceleration using lasers, electron beams, and beam/plasma interactions.

In bringing advanced accelerator-science and technology to individual users, small groups of researchers, and large collaborations, the ATF offers a unique combination of a high-brightness 80-MeV electron beam synchronized to a 2-TW picosecond CO2 laser.

The DOE's Office of Science recently identified the ATF as a flagship facility in their newly established Accelerator Stewardship program. The essence of this program is to apply the particle accelerator expertise of the Office of High Energy Physics (OHEP) and its accelerator R&D community to explore revolutionary new methods of acceleration for discovery science, as well as economical solutions for realizing compact particle accelerators that are essential for many applications in industry, medicine, and other civil ventures.

At this juncture, the ATF has embarked upon a transformational upgrade of its capabilities. We plan to greatly expand the ATF's floor space, and the number of independent experiment halls, alongside upgrading the electron beam's energy in stages to 500-MeV, and the CO2 laser's peak power to 100 TW. This upgrade will afford a new, vast space for the laser and electron beam for conducting new research in accelerator science and technology that is at the forefront advanced accelerators and radiation sources, and to support the most innovative ideas in these fields. There are many emerging opportunities for scientific breakthroughs that include the following: Plasma Wakefield Acceleration (PWFA), extending the researches already pursued at the ATF; Laser Wakefield Acceleration (LWFA) wherein the longer laser wavelengths will engender a proportional increase in the beam's charge, while our linac will assure, for the first-time, the opportunity for undertaking detailed studies of seeding and staging of the LWFA. The laser will extend proton acceleration to the 100-200 MeV level, as is demanded for certain medical applications.
Find more information on the ATF upgrade plans and the DOE's Accelerator Stewardship program on the ATF homepage and at the upcoming Upgrade Workshop.
(extract from a paper by the same authors submitted to AAC'14 Proceedings)

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ATF industrial partners respond to The DOE's HEP Funding Opportunity Announcement in Accelerator Stewardship

I. Pogorelsky, A. Murokh and W. Kimura

The BNL ATF is widely recognized as the premier user facility for performing advanced accelerator R&D using high-power picosecond CO2 lasers. Over the years a number of milestone achievements have been accomplished at the ATF with the most recent examples of the record-breaking IFEL acceleration at 100 MeV/m and observation of multiple harmonics in inverse Compton x-ray scattering (*refer to our Newsletter articles*). The utility of high-power, ultrafast CO2 lasers for the Accelerator R&D Stewardship missions can be greatly enhanced by an increase of the laser's repetition rate much beyond the present operation limit, which is 0.1Hz for a terawatt-class unit.

Two small-business companies, STI Optronics and RadiaBeam Technologies, responded to the challenge, of achieving high repetition rate in such a laser, and to the DOE's HEP Funding Opportunity Announcement (FOA) in Accelerator Stewardship by submitting their two complementary proposals for next-generation high-repetition 10 µm lasers. RadiaBeam Technologies, in collaboration with UCLA and ATF, addresses in its proposal the upgrade of an Optical Parametric Amplifier (OPA), which has been recently installed at the ATF as a source of a MW-power, sub-picosecond, 10-µm seed to the CO2 amplifier chain. A novel combination of additional amplification stages with linear and non-linear compression modules will allow achieving GW-level output in a sub-picosecond pulse in the wavelength range 8 to 12 µm, operating with an initial repetition rate of 10 Hz, and upgradable to >1 kHz. Another collaboration led by STI Optronics (STI) that includes also Pulsed Power Research Group at the Univ. of S. California, SUNY SB and ATF addresses improving other part of the ATF CO2 laser system - high-power laser amplifiers. High-voltage, high-current solid-state switches are now commercially available that can be used to create a high-rep-rate pulsed power circuit to drive high-pressure discharge in CO2 lasers at 100 Hz and beyond. These solid-state switches also have the advantage of long lifetimes. The STI collaboration will design, build, and test a pulsed power circuit based upon these switches and test it on one of the ATF CO2 laser amplifiers.

The combination of these two new potential developments (subject to approval by DOE) will make a decisive step towards next-generation high-repetition CO2 laser technology capable to deliver ultra-short mid-IR laser pulses for Advanced Accelerator R&D and covering a wide scope of applications relevant to the Accelerator Stewardship DOE mission, including those in science, industry, Homeland Security and medicine. Examples include: Remote sensing of gaseous agents; EUV generation for photolithography; and ion acceleration for medical therapy in which high-rep-rate provides faster delivery of the needed dosage. The performance and capabilities of such a new-generation laser source could be explored first in ATF user experiments. One high added value application of the proposed high-repetition 10-mm laser is Dielectric Laser Accelerators (DLA). DLA is a promising laser-powered technology to reduce the characteristic features of relativistic electron beam sources down to the optical scale. DLA technology has been under development for decades, but the concept has recently gained momentum, with advances in solid-state laser technology and nanoengineering methods. A significant milestone was the first experimental demonstration of DLA energy gain, achieved at SLAC in 2013. Transitioning from Near-IR towards mid-IR laser driver for DLA offers several important advantages. Larger structure apertures and stored energies allow higher charges to be accelerated, reducing parasitic wakefields, and allowing moderation of the injected e-beam emittance. In addition, the expansion of gap size relaxes all structure dimensions and fabrication tolerances. Hence, the proposed source development would enable a mid-IR DLA program using ATF's state-of-the-art electron beam capabilities.

Another important mid-IR laser application is high-order harmonic generation (HHG). The principle advantage of using mid-IR versus optical wavelength is that the energy cut-off of the emitted photons is proportional to the laser pulse pondermotive potential, which scales quadratically with the wavelength. The mid-IR DLA and HHG developments, besides their stand-alone scientific and technological values, would also offer an opportunity to validate the proposed mid-IR laser system.

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Single shot double differential spectrum of nonlinear inverse Compton scattering

Y. Sakai, J.B. Rosenzweig, I. Gadjev, O. Williams (UCLA), T. Kumita (Tokyo Met.), and Y. Kamiya (U. Tokyo)

Inverse Compton Scattering (ICS) is an attractive option for development of flexible radiation sources in the X to g-ray spectral regions. This flexibility is due to the electron beam-energy dependence of the maximum photon energy, $4\gamma h\nu_L$, where γ is the Lorenz factor of the electron beam and $h\nu_L$ is the incident laser's quantum energy. The efficient production of ICS photons requires use of an intense laser source. The CO_2 TW-class laser at the BNL ATF, which can be focused to provide peak normalized vector potential a_L of approaching unity, is optimum for

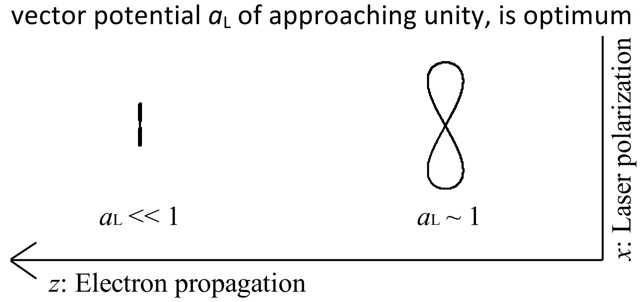

Figure 1. Relativistic figure-8 motion

this purpose. This laser, brought into collision with 50-70 MeV electron beam, enables us to investigate, in a high flux scenario, the nonlinear radiative effects associated with the relativistic figure-8 motion induced in such an intense laser field, which are due to the strong, ***v***×***B*** term in the Lorentz force in this limit (Figure 1).

At BNL ATF, rigorous studies on multi-photon process of 2nd [1], and 3rd harmonic generation [2], as well as spectral study using a *K*-edge [3] and single shot diffraction from Si crystals in the linear regime [4] have been performed in recent years. In the most recent step in this program, in July 2014, the double differential spectrum of nonlinear ICS using a Si-Mo multilayer curved grating [5] has been successfully observed.

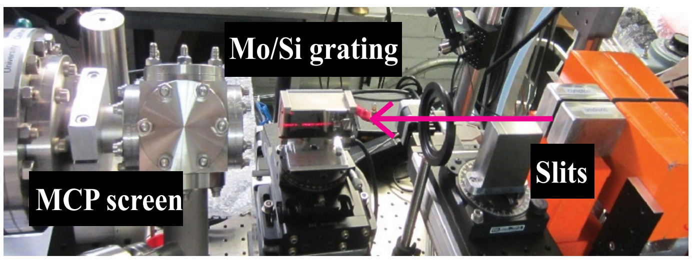

Figure 2. Curved multi-layer spectrometer set up in BL1

In this experiment, a curved grating (Figure 2) consists of 45 identical layers of Si/Mo with $d \approx$ 3-4 nm [5] having curvature of 2.5 m. The dispersed ICS X-rays at energies >5 keV are observed on the KBr coated MCP screen through two Be vacuum windows of 250 μm and ~1 m air path [3]. For this measurement, the ATF's newly upgraded CO_2 laser with stable, solid state seed system having a wavelength of 9.25 µm is collided by a 61 MeV, 300 pC, ~3 ps electron beam, to give a maximum ICS energy of 7.6 keV, which corresponds to a Bragg angle of ~25 mrad.

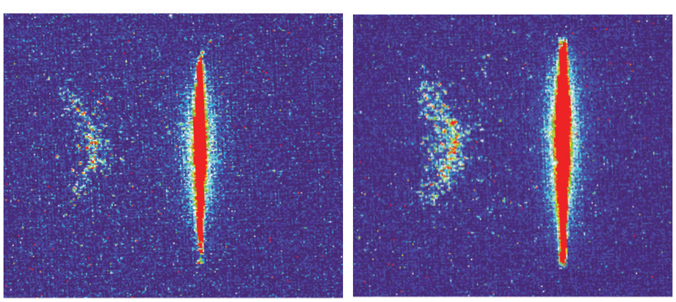

Figure 3. Observed crescent shape double differential spectrum of single shot ICS. Laser's total energy is approximately 1.5 J (left) and 3.0 J (Right).

Figure 3 shows the observed double differential spectrum $\partial^2 I/\partial h\nu\partial\theta$ for the approximate total energy of laser 1.5 J (left) and 3.0 J (right), respectively. For the 1.5 J case, the narrower band linear ICS spectrum has been verified. Note that crescent shape of the double differential spectrum nicely presents off-axis relativistic red-shifting according to the undulator equation hvX-ray ≈ 4γ2hvL /(1+γ2θ2). In the 3.0 J cases, the estimated photon number generated at I.P. is estimated to be approaching ~109. Entering into the nonlinear regime, the so-termed mass shift effect due to strong laser field is observed as broader width of photon energy spectrum for 3.0 J case. This result would contribute to the understanding of the intense monochromatic ICS X-rays or high order harmonic production, as well as strong field physics itself.

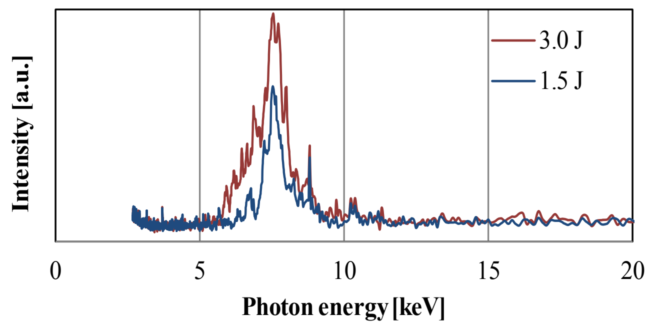

Figure 4. On-axis intensity profiles of spectrum verifies red-shift effect due to electron's mass shift in strong laser field. Laser energy are 1.5 J (Blue) and 3.0 J(Red). Horizontal axis: estimated X-ray energy from measurement.

[1] M. Babzien, et al., Phys. Rev. Lett. 96, 054802 (2006)

[2] Y. Sakai, et al., 3rd order harmonic in inverse Compton scattering, Symposium on Laser-Driven Sources of Particle and X-Ray Beams II (JTh3L), June 8-13 (2014)

[3] O. Williams et al. Nucl. Instrum. Meth. A 608, S18 (2009)

[4] F. H. O'Shea, et al., Phys. Rev. ST Accel. Beams 15, 020702 (2012), [5] Y. Kamiya, et al., X-ray spectrometer for observation of nonlinear Compton scattering, Proc. Joint 28th Workshop on Quantum Aspects of Beam Physics (World Scientific), 103 (2003)

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